

Azouzoute, Alae; Alami Merrouni, Ahmed; Garoum, Mohammed; Bennouna, E. G.

Article

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Soiling loss of solar glass and mirror samples in the region with arid climate

Alae Azouzoute^{a,b,*}, Ahmed Alami Merrouni^{a,c}, Mohammed Garoum^b, El Ghali Bennouna^a

^a Institut de Recherche en Energie Solaire et Energies Nouvelles - IRESEN, Green Energy Park, Km 2 Route Régionale R206, Benguerir, Morocco

^b MEAT, University Mohamed V in Rabat, EST Sale, 227 Avenue Prince Héritier, Sale, Morocco

^c Department of physics, Faculty of Sciences, Mohammed 1st University, 60000, Oujda, Morocco

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Abstract

Solar energy market is still growing in Morocco and in other countries around the world. The development and deployment of any solar project require a prefeasibility study before the establishment of the plant. The most important parameters influencing the site selection or the project feasibility are solar radiation and the climatic conditions. Soiling is a limiting efficiency factor that drastically affect the optical and the electrical performances of the solar plants. The objective of the current study is to evaluate and compare the soiling impact, from an optical point of view, on both PV and CSP technologies by investigating the reflectance and transmittance drop of glass and mirror samples exposed at Green Energy Park research facility (Morocco) during the dry period of the year. The results show that the effect of soiling is very important in the dry period of the year, it can reach up to 35% of soiling loss after only one week for the mirror samples. For the glass samples, the drop can reach up to 12%. Besides, it has been found that the CSP mirrors are three times more affected by soiling than PV glass samples.

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Keywords: Hybrid CSP/PV plant; Soiling; Optical efficiency; Outdoor exposition; Mid-south of Morocco

1. Introduction

The development and deployment of solar energy market is still growing especially in the MENA region. Many countries in the region has launched an ambitious solar plan that will reach 80 GW by 2032 [1]. Morocco has pledged to satisfy 52% of his energy mix from renewable sources by the end of 2030 [2]. To do that, the kingdom has launched a Moroccan solar plan that aims to install 2 GW of solar power plant. Noor complex project in Ouarzazate is the first big pioneer of solar technology with four parts. The 160 MW Noor I parabolic trough plant with 3 h of storage which is already operational, and Noor II the second part of parabolic trough power plant with a

* Corresponding author at: Institut de Recherche en Energie Solaire et Energies Nouvelles - IRESEN, Green Energy Park, Km 2 Route Régionale R206, Benguerir, Morocco.

E-mail address: azouzoute@iresen.org (A. Azouzoute).

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capacity of 200 MW and will inject electricity in the grid by the end of 2019. Noor III is a central tower plant with a capacity of 150 MW equipped with 7.5 of molten thermal storage, as for the fourth part of the complex, Noor IV is a 70 MW photovoltaic power plant (PV). Moreover, the Moroccan Agency for Sustainable Energy (MASEN) has prequalified five companies to select potential developers of two hybrid solar plant (PV and CSP) at Noor Midelt, which each will have a CSP gross capacity between 150 MW and 190 MW, the PV capacity will be optimized by the subcontractor [3].

The selected sites for the deployment of this project are known with their dry and harsh climatic conditions. The operation and maintenance (O&M) is the second important parameter that influence directly the Levelized Cost of Electricity (LCOE). According to the investigation carried out by the NREL (National Renewable Energy Laboratories) the operation and maintenance of the solar field is about 23% from the total O&M costs.

In fact, the most suitable sites for the installation of CSP and PV plants are commonly affected with harsh climatic conditions especially those related to the accumulation of dust. Dust is an important factor that affect the optical efficiency of solar mirrors and the surface of solar panel for CSP and PV technologies respectively, which consequently affect the electricity production.

The objective of this study is to evaluate the impact of dust accumulation on both PV and CSP technologies, if installed in the same location, by measuring the drop of the reflectance and transmittance for mirror and glass samples respectively exposed at Green Energy Park research facility (Morocco) during the dry period of the year.

2. State of art

Knowing the importance of the soiling phenomenon and its critical influence on the solar field, several previous studies have revealed the importance of the effect of the site climatic conditions on the soiling rate over the solar reflectors and PV panels especially in Morocco. We cite for instance, Merrouni et al. [4] that presented a three-month study of the soiling effect on glass and aluminum mirrors exposed in eastern of Morocco. The results show that for different tilt angles the most affected one was the mirror exposed at horizontal position with 45% and 33% of cleanliness drop for the glass and aluminum mirror respectively. Bouaddi et al. [5] have concluded that the aluminum mirrors can be suitable materials for solar reflectors in the arid region, especially considering their significant efficiency against soiling during the summer period in comparison to the glass mirrors. Azouzoute et al. [6] have evaluated the soiling effect for the dry period of the year on the electrical production of a CSP plant under the climate conditions of Benguerir, the results show that the electrical production decrease up to 22% after two weeks without any cleaning of the solar field. On the other hand, for PV technology [7] have evaluated the impact of soiling on the surface of a front-glass PV panel. The results show that the soiling rate can reach up to 18% for a period of exposition between 25 July and 2 August 2016. Nevertheless, as we have mentioned above that Morocco has pledged the installation of two-hybrid power plant with CSP and PV technology. The reason that we need to understand the impact of dust on the performance of different technology installed at the same site in order to find the best cleaning strategy for hybrid plant.

3. Methodology

In order to evaluate the impact of dust accumulation for hybrid CSP and PV power plant we have investigated the effect of soiling on the optical efficiency of mirror and glass respectively. To do that, we have installed the mirror and glass samples (with dimension of 10×10 cm) side by side on a fixed rack facing south with 1m above the ground and inclined by 32° (see Fig. 1.). The samples were exposed during the dry period of the year for 3 months, from the 1st of June until the 31st of August 2018. The site is equipped with high precision meteorological station allowing measurements of different weather parameters. In order to characterize the amount of soiling on the surface of mirror and glass samples we have measured respectively the drop of specular reflectance and transmittance. The Device & Services R15 reflectometer “D&S R15” with an acceptance angle of 25 mrad has been used to measure the loss in the mirror’s specular reflectivity, and the spectrophotometer “LAMBDA 1050 UV/Vis Spectrophotometer” was used to quantify the drop in the transmittance values for the glass samples. Besides, to quantify the density of dust accumulated on the surface of each sample we have weighted the samples with the “Kern ABT analytical balances”. Each week, the exposed samples were collected and preserved in a petri-dish box. In the first step, we cleaned the bottom and the borders of the samples and then we weighted the samples in a dirty state (with the analytical balances) in order to quantify the density of dust deposition on the surface of each tested sample. After

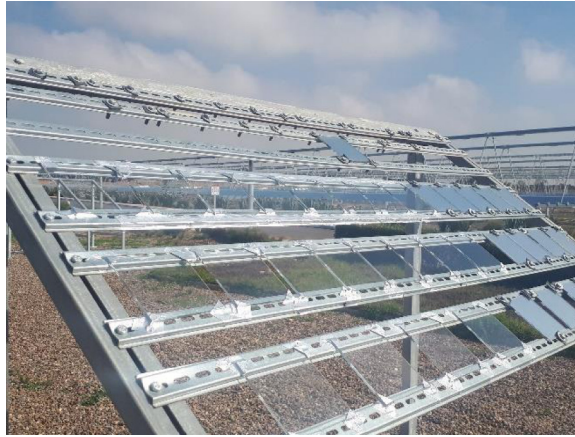


Fig. 1. Glass and Mirror samples installed at Green Energy Park.

that, and to take into consideration the dust inhomogeneity distribution on the sample's surface, we measured their specular reflectivity of the mirrors in five different spots and we measure the transmittance in three different point. After cleaning, we repeated the same series of steps for the mirror and glass samples.

In order to quantify the soiling drop for each sample we have calculated two different parameters; first, the cleanliness Eq. (1):

$$\text{Cleanliness} = \frac{\rho_d}{\rho_0} \text{ or } \frac{\tau_d}{\tau_0} \quad (1)$$

where ρ_d is the specular reflectivity in the dirty state and ρ_0 is the specular reflectivity of the clean state of the last week inspection. Besides, τ_d is the transmittance value for the dirty state and τ_0 is the transmittance value for the initial clean state.

And second, the percent soiling loss Eq. (2):

$$\text{Soiling loss} = (1 - \text{Cleanliness}) \times 100 \quad [\%] \quad (2)$$

4. Results & discussion

4.1. Effect of soiling on optical performances

Fig. 2. illustrate the soiling loss on the optical performances of glass and mirror samples exposed at Green Energy Park from June to the end of August 2018. As it can be seen from the figure, the mirror samples were most affected with dust than glass samples with an average of 22% for all the period of the experiment until 17 August 2018 (11 weeks). The results in Fig. 2 show a gap for the period from 17 to 24 August, the reason that we have not removed the samples and we have expose them for two weeks until the end of the experiment (the last measurements are done for two weeks from 17 to 31 August). Thus we can noticed that the soiling loss have shown an increase for mirror samples that reach up to 39% and 14% for glass samples. Besides, the most important factor that influence the soiling for both technology is the climatic parameters such us relative humidity and rainfall. We can illustrate from Fig. 2 that the samples were more affected with dust during the test period from 27 July to 3 August in comparison to the last weeks. This can be explained by the light precipitation in the 2nd of August (see Fig. 3.). This small rain quantity has an opposite effect on the cleaning if it coincides with high aerosols concentration in the upper atmosphere. This phenomenon is known as “red rain event” [8] and [9].

4.2. Dust deposition

Fig. 4. show the density of dust deposition for the glass and mirror samples during the period from the first of June until the end of August 2018. As it can be noticed from the figure, the glass samples were denser with the

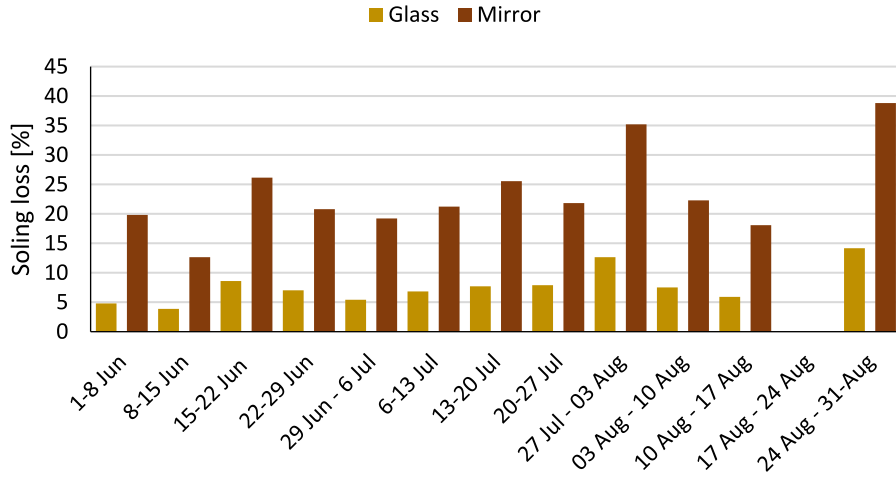


Fig. 2. Soiling loss in percentage on the surface of the glass and mirror samples for the period from 16-Feb-18 until 8-June-18.

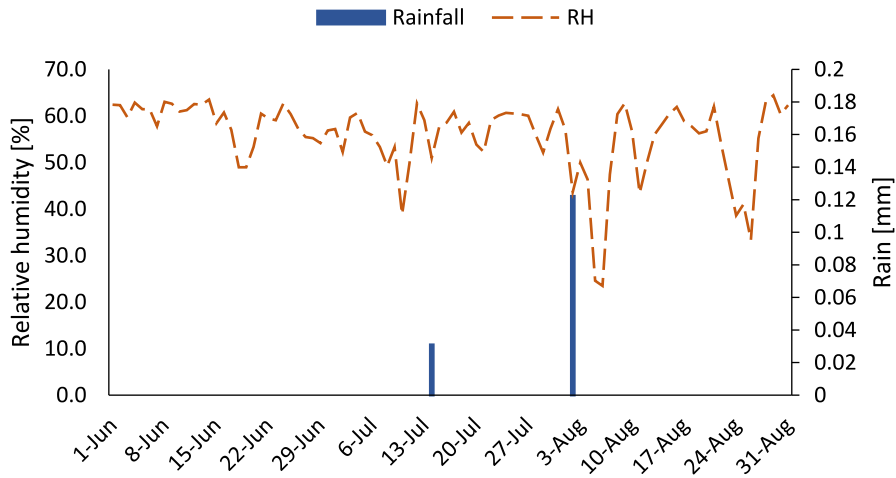


Fig. 3. Average relative humidity and total rain accumulated during the period from 1-June to 31-August 2018.

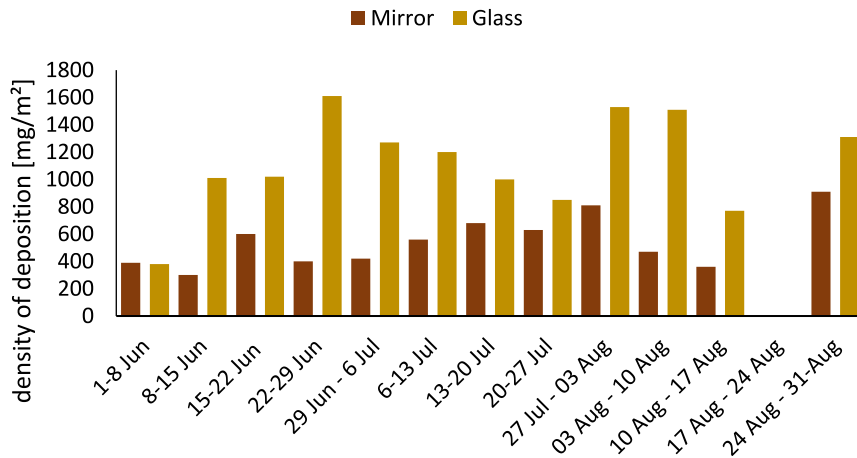


Fig. 4. Density of deposition for the glass and mirror samples during the test period.

accumulation of dust particle on their surface. This disturbed pattern in comparison to the results of the soiling loss where we found that the glass samples show less soiling loss in their transmittance values. In fact, it can be explained by the surface properties of each sample whether it is glass or mirror. This amount of dust on the glass samples is due to their surface roughness' which is rougher in comparison to the mirror samples where the glass pane on top of the silvered reflected surface are very well polished to reflects more light. The agglomeration pattern of dust particles on the glass surface as it can be seen in Fig. 5. where dust particles are agglomerated on the surface with homogeneity with a small spot due to the light rain on the day of 2 August (week from 27 July to 3 August). In contrast, for the mirror samples we can see that dust particles are agglomerated on the surface as a big stain.

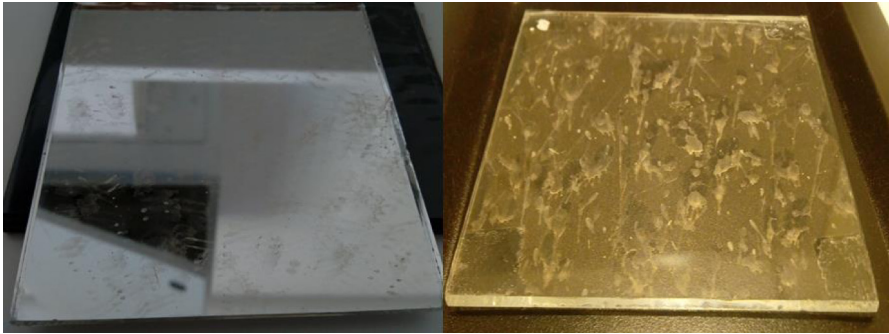


Fig. 5. Dust particles deposition pattern on the glass and mirror samples (27 Jul – 03 Aug).

Moreover, we can explain the difference on the soiling loss on the specular reflectivity of the mirror samples in comparison to the transmittance of the glass samples by the path of the incident ray on the surface of each of them. Indeed, as it can be seen in Fig. 6(a) at the presence of dust on their surface the mirror's surface, at the first contact between the incident rays I_0 , a part of this light will be scattered due to the Mie scattering phenomenon when part of irradiation is diffusely reflected I_{diff} and the other part is scattered $I_{scat,1}$. The remaining intensity will afterward's be transmitted be reflected by the silver layer (Ag). At its way back to the receiver tube, a second contact between the reflected light and the dust particles occurs causing another drop second scattering $I_{scat,2}$ in the ray's intensity, thus on the energy reaching the receiver tube as a specular reflected irradiation I_{ref} which is the usable portion of light. This is not the case for the PV technology (as it can be seen in Fig. 6(b)), where the transmitted light after the first interaction between the incident irradiation and the dust particles will reach the cells and produce electricity with the transmitted light ($I_{T\ direct} + I_{T\ diffuse}$).

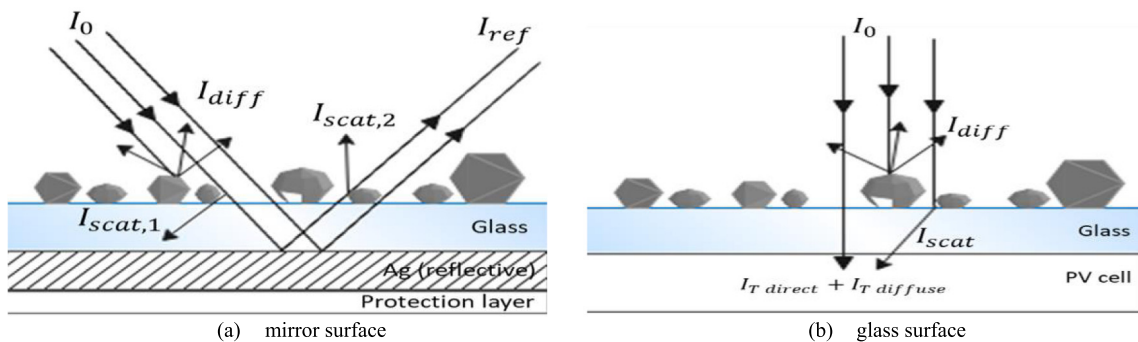


Fig. 6. Optical soiling losses for the mirrors and glasses samples.

5. Conclusion

The development of solar energy is still growing all around the world, which require a deep understanding about the parameters that affect drastically the efficiency of the solar power plant. Morocco and Australia has pledged to install a hybrid CSP–PV solar power plant, thus, the importance to evaluate the impact of soiling on the energy production of both technology especially those operational under the same site climatic conditions. Many studies

have been done the last years to emphasize the effect of soiling on the energy efficiency for each technology separately.

In fact, there is no study that elucidate the impact of soiling on a hybrid solar plant and properly on mirrors and glass for CSP and PV technology respectively. However, in this work we aim to understand and to evaluate the direct impact of soiling parameter on the optical efficiency of solar mirror and glass samples installed at the same site at Green Energy Park in the mid-south of Morocco for the dry period of the year. The results show that the mirror samples was three times more affected with dust than the glass samples. The soiling loss can reach up to 35% for mirrors with the opposite effect of light rainfall when it coincides with high concentration of aerosols on the upper atmosphere.

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